# Open Source Cookstoves Library for Massive DIY Deployment

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***Abstract*— A library of open source clean cookstoves reference designs are built to tackle the problem of household air pollution due to use of dirty burning solid fuel stoves. The designs are optimized for massive DIY deployment supporting easy adoption, transportation, assembly, and maintenance.**

**The initial reference designs include a DIY concentrating solar cooker, biomass stove, and tools for making alcohol stove. Construction is based on standards-based off-the-shelf material and common power tools found in hardware & construction material stores, and home-made or 3D-printed tools. This library empowers grassroots or micro-entrepreneurs to build high-performance and low-cost clean cookstoves without investing a fortune on production machinery. Workshop material on clean cookstoves principles, OpenSCAD 3D design, and DIY construction methods equips people with the needed knowledge and skills. A visit to hardware and materials stores is what it takes for local NGO or users to get started.**

**With both clean cookstoves and construction tool designs, the library forms a basis for design engineers to collaborate and speedup efficiency improvement, for organizations seeking clean cooking solutions to drive universal adoption, and for decision makers to work out deployment and finance schemes for their projects.**

***Keywords—clean cookstoves; open source; grassroots; concentrating solar cooker; HIO***

## I. Introduction

About 2.7 billion people, or 40% of world population, are using dirty solid-fuel stoves as their main means for cooking. According to a recent World Health Organization report [1], casualty due to HAP (household air pollution) resulting from inefficient solid-fuel cook stoves amounted to about 4.3 million deaths in 2012, making it one of the top causes in premature death, and exceeds that of many well-known deceases such as HIV/Aids and Malaria. In addition, the gaseous and particulate matter emissions are also causing significant deterioration of global warming. The carbon soot also leads to melting of permafrost and various humanitarian crisis. However, the greenhouse effect from existing biomass stoves can be reduced quickly if clean cookstoves are used, whereas even if we stop using fossil fuels now, $CO_2$ level will stay at current level for centuries. So the rapid transition to clean cooking solutions is both urgent and offers quick return from our actions. Therefore, clean cooking solution is identified by United Nations [2] as one of the High Impact Opportunities (HIO) under the sustainable energy for all (SE4all) initiative, and strategies are formulated to facilitate its realization.

The task, making the changes to clean cooking solutions for 40% of the world population in a decade or two, is also unprecedented. As such, the design and implementation of clean cooking solutions should be geared towards rapid massive deployment. For the benefit of target communities with minimal disposable income, it would be better if massive deployment can be achieved with DIY (do-it-yourself) means, this departs from the general practice of having DIY as a means of self-education with little emphasis on quality and efficiency. For this library, every element of product lifecycle is reviewed with an aim to speed up the process and enlarge the degree of impact.

There are already a large selection of clean cooking solutions and there are also improved cookstoves programs held before. Many programs and designs are open sourced. However, we noted open source hardware is very different from software. There is no well-established languages to code the designs. The nearest thing is technical drawing. But unlike software, it is non-trivial to turn a design drawing into a physical object that can come alive like software running on a computer. The commonest form of open source hardware documentation is now a construction instruction that breaks down the process into steps for a skilled worker to build accordingly. This limitation explains why open source hardware do not proliferate widely like software.

We worked out the means to make open source hardware come alive. We found the OpenSCAD 3D CAD software which describes 3D objects with a language structure like software. So the designs can be distributed in open source portals such as Github (github.com) & Sourceforge (sourceforge.net), riding on the infrastructure of these portals for updates and version management. For field deployment, we make extensive use of off-the-shelf tools, standard parts, and commodity materials. These generic parts and corresponding DIY tools can be obtained at low cost due to mass production. Designs built with standards based commodity materials can also inherit performance guarantee. For example, a biomass stove design using fire-protection panels will have fire resistance and thermal insulation properties inherited from the characteristics and fire rating certifications of the material.

In addition to the designs, we have also built tools to ensure consistency and speed of construction while reducing the skill level needed. To achieve this, we make extensive use of 3D printing in tool design. So deployment involves just sending over the design file, assembling the tools with standard parts if needed, and construction can be done in a remote deployment site with ease and precision as designed.

Aprovecho Centre has kindly published a performance benchmark [3] result of cookstoves, mainly for biomass and fossil fuel cookstoves. Based on their findings, we identified 3 broad categories of promising designs. The first is improved biomass stove that burn with substantially reduced emission compared with open fire cooking; the second is alcohol stove which can be easily made to burn cleanly with DIY [4] methods; the third is concentrating solar cooker with the ultimate zero-emission promise and have performance comparable to traditional cookstoves. In our library, we have reference designs and corresponding construction tools for these three categories as a starting point for others to build on.

## II. The Ring-ring solar cooker

One solar cooker design is elaborated in this paper. Thanks to the Solar Cooker International Network, they have maintained a constantly updated Wiki of many good solar cooker designs and plans. The Fresnel reflector type that Volunteer in Technical Assistance (VITA) designed in the 60's [5] was carried by Ed Norman in 1980 to Peru. Today, it is still one of the best solar cooker topology, concentrating sunlight with 4 concentric conical rings of reflectors which is quite easy to implement with simple hand tools. Our solar cooker reference design is also based on Fresnel reflector and includes a kitchen format cooking bench to attract adoption.

### A. Design choices

The "Ring-ring solar cooker" is a concentrating solar cooker that is designed for massive deployment and DIY implementation using low-cost, mass-produced material and tools. The target power of a small and large cooker are 600W

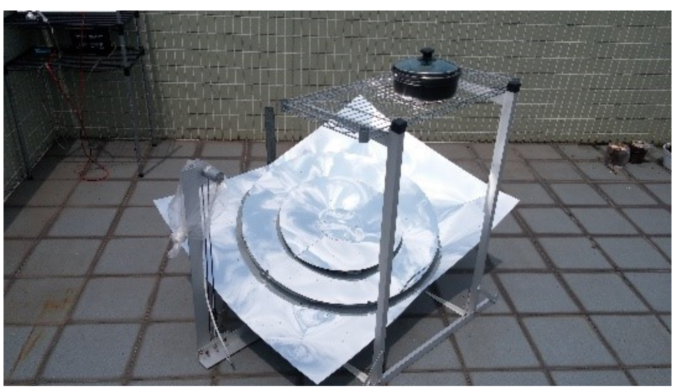

Fig. 1 The small size cooker with extended outer ring, cooking bench, and cooking pot.

and 1800W respectively. The required reflecting surface area is about 1 and 3 square meters.

Our reference design uses mainly aluminium profiles, in particular right-angled profiles which can be stacked up for easy transportation. Aluminium price is near a historical low point of less than two US Dollars per kilogram and very easy to recycle. It is also easy to work with. To support quick DIY implementation, we take advantage of modern power tools and material that can be purchased in hardware stores. The Lithium battery powered electric screwdriver and drill is a must. They can drill holes in just a few seconds and a few hundred holes in one charge. Just clamp the pieces of material together, punch the hole center, and then a self-taping screw can be used to drill the hole and join the pieces together in one action.

Other materials may also be used. But the clamping may not be as convenient. What's more, angled aluminium profiles have other features desirable for quick DIY work. For profiles with thickness less than 1.2mm, it can be cut with simple cutters more quickly and silently compared to using saws, yet this thickness is enough to build a strong support structure for the concentrator rings. Another virtue of aluminium profiles is that they are light and can be packed into very small size for shipping.

The reflecting sheet material may use UV resisting plastic sheets of 0.5mm or 1.0mm, which can be shipped in rolls or stacks. A few hundred sets can be shipped in a pallet of aluminium profiles with accessory parts and another pallet of reflector rolls or stacks. With a rough estimate, a small reflector assembly of one square meter surface with associated supporting frame and stand weighs about 4kg. A standard container can carry over 20 tons of goods. So one container can ship several thousand sets of the core structure material while sourcing locally for the cooking stand. If both the ring stand and cooking stand are built with aluminium, we can still deliver over a thousand pieces or two in one container, with very low shipping cost per unit. This makes our reference design well suited for massive deployment.

Based on the above design choices, we believe it is possible to install up to a few thousand sets of solar cookers to anywhere in the world with adequate sunlight and transportation means to deliver a container of goods. The use of power tools are quite straightforward. A one-day briefing and demonstration should be sufficient to train up local youths to help in the implementation. Another half day is needed to set up a batch production line. With sufficient workshop tools for the people, a batch of solar cookers should be able to complete within one week.

### B. Ring concentrator design

Compared with parabolic concentrator or optical lens, the ring structure of Fresnel reflector tends to be more easily built to high precision by hand tools. On the other hand, it is the more tricky mathematics that blocked people from building one from scratch. So a spreadsheet to calculate the focal length and spot size of a ring structure is provided to simplify the design of Fresnel reflectors. It solves the tricky issue with light blockage of neighboring rings and convenient numbers are used with a little sacrifice of exactness. It is targeted for convenience of use.

The parameters for a ring structure having 4 rings designed for a 0.9mx1.2m mirror sheet are provided, with an extra partial ring if the periphery material from a rectangular sheet is also used. A large middle void is used to trade for narrower rings, and hence achieve smaller cooking spot diameter of about 12cm. Since construction imprecision is inevitable, and sunlight is not illuminating from the center axis, the actual spot size is a bit bigger, suitable for cooking pot diameter of 15cm to 20cm.

The designer can modify the first three rows of the spreadsheet to suit the situation and the lower rows will be calculated. This spreadsheet assumes a flat cooking pan bottom, it is possible to modify the parameters or formulae for other cases.

To build the ring structure, cut rings according to the ring parameters and make the necessary overlap to join the rings. Draw circles on the support structure according to the base radius calculated,

| Formula | Name | Symbol (unit) | 1st | 2nd | 3rd | 4th |
|---|---|---|---|---|---|---|
| User input value | Inner radius | Rir (mm) | 70 | 190 | 310 | 435 |
| User input value | Outer radius | Ror (mm) | 190 | 310 | 435 | 560 |
| User input value | Outer overlap | Pw (mm) | 4.5 | 25 | 70 | 140 |
| Pwi = Pw * Rir/Ror | Inner overlap | Pwi(mm) | 1.7 | 15 | 50 | 109 |
| Ps = 2*sin$^{-1}$(Pw/Ror/2) | Sector overlap | Ps (rad) | 0.024 | 0.081 | 0.161 | 0.251 |
| Ma = cos$^{-1}$(Rib/Rir) | Mirror angle | Ma (rad) | 0.087 | 0.160 | 0.227 | 0.283 |
| | Mirror angle | Ma (deg) | 5.0 | 9.2 | 13.0 | 16.2 |
| Mrh = (Ror-Rir) * sin(Ma) | Mirror rim height | Mrh (mm) | 10.4 | 19.2 | 28.1 | 35.0 |
| F = (Ror-Rir)/2*sin(Ma) + (Rib+ (Ror-Rir)/2 * cos(ma)) / tan(2*ma) | Focal length | F (mm) | 742 | 745 | 742 | 742 |
| D = (Ror-Rir) * cos(Ma) / cos(2*Ma) | Spot size | D (mm) | 121 | 125 | 136 | 142 |
| Rib = Rir * (1 – Ps/(2*pi)) | Base inner radius | Rib (mm) | 69.7 | 187.6 | 302.1 | 417.6 |
| Rob = Ror * (1 – Ps/(2*pi)) | Outer radius | Rob(mm) | 189.3 | 306.0 | 423.8 | 537.7 |
| B = sqrt((Robi-Rib)^2 + Mrhi^2)/ cos(Ma)*sin(2*Ma+atan((Robi-Rib)/Mrhi)) | Blockage width | B (mm) | 0.0 | 5.0 | 12.3 | 21.2 |
| Fb = F + B/2 * cos(Ma) / sin(2*Ma) | Adjusted focal length | Fb (mm) | 742 | 753 | 756 | 761 |
| Db = D - B * cos(Ma) / cos(2*Ma) | Adjusted spot size | Db (mm) | 121 | 120 | 122 | 118 |

Table 1: Spreadsheet for Fresnel reflector parameters calculation

then fix the rings to the marked circles. The mirror rim height parameter provides cross checking on the quality of alignment, which can identify imbalance of mounting and gross mistakes in ring dimensions and overlap. When properly done, the rings will be aligned to the calculated focal lengths with the indicated spot diameters. In actual implementation, distortion and misalignment results in bigger overall spot size.

Currently, we found a polycarbonate (PC) mirror sheet of size 3x6 feet (0.915x1.22m). Based on this, one implementation will be cut from 3x4 feet sheet so that 2 pieces of sheets can be used to build 3 solar cookers. Another suitable size is to use two pieces for one solar cooker of diameter about 1.8m.

Even with so few number of rings, the concentrated spot of a reflector based on above parameters, with calculated value of 12cm, should be no more than 20cm in actual handmade implementation. This size matches the bottom of a typical cooking pan or kettle, creating enough solar concentration without being too concentrated to be dangerous. Put a hand at the focal point and you can feel the heat, but have no problem withdrawing before being roasted. This inherent safety is also important for open source designs.

Putting this spreadsheet as open source design for concentrated solar cookers is very empowering. Now product designers can work on the other parts of the design and be rest assured that the finished design can get a concentrated solar spot of the right size at the right position. This spreadsheet is certainly not the best, and may be far from perfect. But it doesn't matter. The calculation will be put in the public domain for others to improve. In the meantime, it provides a degree of certainty for the designers.

The rings can rest on any platform that the designers desire. It can be a flat surface. But a frame structure is lighter and can let wind pass through without undue damage. A hexagonal structure is found to be very rigid and can be built with right angled aluminium profile to create a light and strong frame.

Fig. 2 Hexagonal frame structure for the rings created a very light and rigid structure

For the 0.9mx1.2m reflector assembly using 0.5mm polycarbonate sheet and aluminium profile of thickness about 1.2mm, the weight is about 1.8kg with the aluminium frame accounting for about 70% of the weight. This is among the lightest rigid concentrating reflectors. With this lightness comes many virtues. It can be dismantled in one minute with release of a single screw for carrying inside the house during bad weather, thus greatly increasing its life. Another virtue is possibility for low cost automated control.

### C. *Reflector stand and sun tracking*

The reflector is set to rotate along the axis of earth's own rotation by mounting to the stand at an angle equal to the latitude of the location for time-of-day sun tracking。 Due to the reflective structure, deflection is doubled and so the rotation should be at half of solar revolution speed, or 7.5 degrees per hour. Due to the light weight of the ring structure, we can make a simple rotation mechanism using a door hinge. Its rotation can be linked to a clockwork or solar cell based feedback system. There are designs of sun tracking circuit on the web with two counteracting solar cells. The reflector will stay in the position when the output from the two solar cells balance out. Although its output power is not impressive, such designs are sufficient to move the light reflector assembly.

*D. Cooking pan stand*

The first design is configured to be facing up for convenience of testing in Hong Kong. This configuration is good for people living near equator, which coincidentally covers a large proportion of disadvantaged communities using biomass stoves. Hong Kong's latitude is about 23 degrees North and the cook will be standing on the North side facing south.

The concentrated sunlight is directed to the bottom of a cookware on a cooking bench like that of a kitchen to reduce resistance of adoption. This cooking bench is placed in front of the ring structured reflector assembly and can be built with local material and normally will not affect performance.

For this configuration, cooking bench height is 0.95m and focal length of reflector assembly is 0.75m. This is suitable for cooking in a standing position. For the large reflector assembly with design focal length 1.0m, a bench height of about 1.3m is needed. A stepping bench of about 0.4m is needed for the cook to stand on. The benches can be built from local material. The top of the cooking bench is placed a wire mesh which allows sunlight to pass through while supporting the cooking pan or kettle.

A conical sheet mirror funnel may be added around the cooking pan to collect sunshine just off position, and to provide a certain degree of protection for the cook. The main value of this funnel is to allow less often adjustment when manually tracking the sun. There is no danger of burning the cook because the sunlight is not very concentrated, especially outside of the focusing plane. However, it may hurt the eyes.

The position of the cooking pot stand can be anywhere close to the perpendicular to the axis of time-of-day rotation with enough offset to reduce possible blocking of sunlight from illuminating the reflector but not too much as to reduce the projected aperture to capture sunlight and distort the concentrated solar spot. The following shows some possibilities

From Equator to about 30 deg. North, the cook should be facing South. About each week, the angle of tilt for the rings should be adjusted. Each day, the rings are rotated sideward to follow the sun. During summer, the cooking bench may partially block the sun near noon, which is acceptable since sunlight is strongest at that time. This can be avoided if the rings are placed further away from the bench in summer time and bring partially underneath the bench in winter time.

If the cooking bench is easily movable, which should be the case, it is also possible to place it to the West of the reflector in the morning, then move to the East side of the reflector in the afternoon.

From latitude from about 30 deg. or above North, a standing reflector ring assembly can give better result during winter time and the cook should be facing North. In that case, a secondary reflector is needed to direct the frontal light to go up. It is also preferable to have longer focal length to reduce light blockage and hence achieve higher utilization of reflector surface.

*E. Production considerations*

One prevailing advice in humanitarian projects is to use locally sourced material and labor. We believe this advice must be critically assessed and not to follow dogmatically in order to achieve rapid massive deployment. We see that mobile phones are transforming the lives in the developing world. Yet this is not possible if we follow the local sourcing advice. Likewise, we see many good designs not scaling up as fast as it can be due to adherence to this advice. We have studied many solar cooker plans and find that most require skilled technicians to work for quite long time to implement. For example, there are many instructions teaching ways to glue a reflective material on a backing sheet which is a laborious process with uncertain quality of the resulting surface. For a bit higher cost, we can use good quality sheet plastic mirrors or coating protected aluminium sheets for robust or high strength implementation.

For the solar cooker stand, while the precision and strength requirements are low, we can use local material. Mass produced parts and materials are used without hesitation if they provide the desired quality we need. Power tools are used to reduce labor needs instead of slowing down deployment for the sake of creating temporary local jobs.

Our reference design uses mainly aluminium profiles as structural material. Right angled profiles are used liberally because they can be easily found and comes with a full range of width typically up to 65mm and thickness up to 3mm. The thicker ones can be cut by electric saw or hack saw whereas those of 1.2mm or thinner can be cut like paper using metal cutter. They can be joined easily with rivet, bolt and nut, or self-taping screws. A hexagonal structure can be built easily with such profiles.

Fig. 3 Jumbo ring cutter with cutter tool bit

*F. Jumbo Ring Cutter and compass*

Another factor in speeding up implementation is production tooling. The rings form the soul of this solar cooker. So finding a way to make the rings precisely and efficiently merits our attention.

It is nowadays easy to cut sheet material into any shape using flatbed laser cutter or other industrial CAM tools. However, it is not cost effective to ship such tools to the deployment site. It might not even be desirable to have the sheet material be cut in factory and then ship to the deployment site because it is often much easier to handle a roll or a stack of sheet material than to handle the individual pieces large and small.

In order to accelerate the cutting of the concentrator rings on site without the benefit of industrial cutting tools, a jumbo cutting tool was designed using a 3D printed block that puts together the cutter blade, pencil, the aluminium arm, and associated bolts and nuts. If only fixed lengths are needed, the ruler can be replaced with a simple thin strip. For larger production batch, multiple cutters will be used with each setting to the size for one radius. The marking of base circles on the support frame can be done with a thin strip with holes drilled at the desired distances and pencil or ball point pen can be inserted to draw out the circles. For producing just a few pieces, we only build this simple compass. With proper choice of tool bit, this tool can cut out a circle on a diverse range of sheet materials in a minute or two.

The jumbo ring cutter and strip compass are not great innovations. It is up to the open-source design community to come up with better and more cost effective tools in future. Nevertheless, it has dealt with the lack of strength for 3D printed parts by incorporating embedded nuts and screw head. It combines the precision of 3D printing with strength and special features of mass produced hardware parts to deliver needed tools for deployment without actually shipping the hardware. This version of tools is doomed to be the worst in the series of tools to be designed. But from this humble starting point, we can already assure a high precision for the reflector assembly, which cannot be dealt with using readily available off-the-shelf tools. They are highly affordable, easy to build, and yet greatly enhance productivity and quality for small to medium batches, which is a vivid illustrion of our principle to achieve massive deployment with DIY means.

## III. ALCOHOL STOVE

Alcohol is a very unique fuel in that it can be burnt cleanly without much optimization in cookstove design. Alcohol stove has a very unique characteristic in that it can be built at

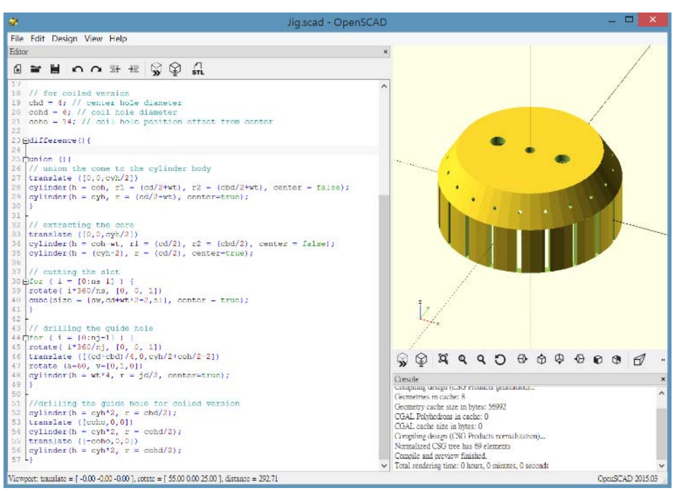


Fig. 4 Design of drilling jig with holes for punching a ring of holes on the DIY beverage can stove

extremely low material cost. Make a search on DIY alcohol stove and you can find hundreds of tutorials and videos to show you how to build one with a beverage can. Basic designs have efficiency of about 40% and more elaborate designs such as those having a wind shield and well implemented can achieve over 60% efficiency, which is far better than the 10-15% of three-stone open fire cooking. However, most of them require use of delicate model making tools, skill, and patience to build. We find that the skill requirements can be greatly reduced by 3D printing of certain jigs & fixtures.

One key step in making the alcohol stove is to make a ring of about 20 small holes of diameter 0.8mm to 1.0mm. This is achieved by designing a drilling jig covering the beverage can body with a ring of holes opened at designed locations. The drilling can be done with electric screwdriver. Hand drill used by model makers works better for such small holes, but is slow and requires practice. A simpler and faster way is to use sewing needle which can be purchased in a range of diameters from 0.5mm to 1.5mm at low cost. On the other hand, there is no suitable pushers in hardware stores for punching of these holes.

Fig. 5 Using 3D printed drilling jig in beverage can alcohol stove construction

For larger batch production, more tools can be developed to further speed up the DIY construction process. For example, we can make tools to cut out the alcohol stove body of designed height.

With the tools in place, people with basic tool handling skill can build alcohol stoves precisely as designed just like a pro. The custom designed tools will possibly enable them to do it even faster than skilled modelers.

In the United States alone, over 100 billion beverage cans [6] are consumed each year. The consumption for one week is enough to provide each family using solid fuel stoves with one alcohol stove for clean cooking. With customized DIY construction tools, there is also no problem in producing enough for the whole community in a few days.

Like the razor blade idea, the availability of tools will create a market for the consumable item for long term business. There is already ample supply of alcohol for transportation and industrial use, staying at about 100 billion liters a year in the last decade. Diverting a small portion from transportation fuel to cooking fuel can greatly reduce air pollution and help in controlling climate change, as well as a profitable business move for ethanol producers.

For some regions with growing of corn or sugar cane, alcohol can be produced locally via micro-distillery workshops producing from a few hundred to a few thousand liters of alcohol per day at competitive cost, which produce multiple benefits for the local community. Micro-distillery can be cost competitive [7] with industrial scale alcohol producers by tapping into local feedstock supply and fuel demand which can't be economically accessed by large organizations as well as enjoying lower transportation cost and shorter supply chain. In future, cellulosic alcohol will enable local supply of alcohol from waste for many more regions around the world.

As shown above, alcohol stove can be massively deployed with negligible cost faster than any other kind of stoves, and can tap into the existing infrastructure of alcohol fuel production while fostering the future development of more cost-effective local fuel production.

## IV. BIOMASS STOVE

There are many good biomass stove designs, notably the rocket stove characterized by a chimney-like combustion chamber to facilitate more complete combustion of fuel. Among the different implementation methods, the brick type stove is the most straightforward to build and document. A reference design was built that use 20 pieces of standard size bricks. The actual size of the bricks is not very important with variation from place to place. Nevertheless, the aspect ratio is in general approximately 1:2:4. So the structure still applies for most bricks that only deviate a little bit from this popular ratio.

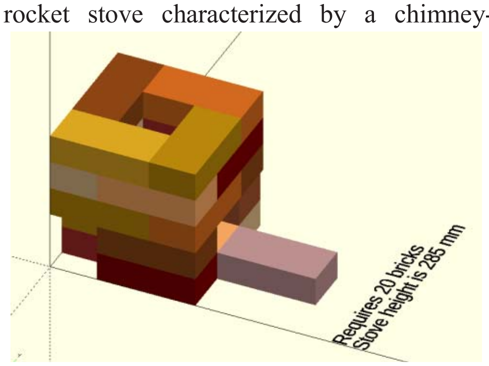


Fig. 6 Reference design of brick type rocket stove

Along the massive DIY deployment principle, we have made a design using 9mm thickness fire protection panel with inner mica lining and metal structural poles to form the L-shaped rocket stove structure. It is easy to build and light in weight. The good heat insulation and small mass greatly reduces heat wasted in heating brick type stoves, which gives it the added benefit of quick to start and hence reduces fuel wastage.

Fig. 7 Rocket stove built with fire protection panel, a common building material.

Biomass stove does not require a change of fuel source. Just that a better design will reduce fuel consumption and toxic emission. So it is worthwhile to promote cleaner burning biomass stoves to ease acceptance although it is very likely to be serving a transitional period. Nevertheless, this may be a crucial step to help those affected by household air pollution to start improving their livelihood by immediately improving their financial and healthy condition.

## V. WATER BOILING TEST

The commonest method to assess the performance of a cookstove is the water boiling test [8]. The Gloabal Alliance for Clean Cookstoves has summarized test results [9] mainly for fuel based cookstoves. It is interesting that electric cookstoves are not included. We shall do water boiling test for all common energy and stove types as a benchmarking reference, including electric stoves. While the comprehensive test is not yet done, preliminary trial with some electric appliances get some less intuitive results. The test with about 800ml of water are : microwave 51%, induction cooker 80%, and electric kettle 88%. We shall perform test with other commonly found cookstoves such as butane gas, paraffin and alcohol gel types which are widely used in restaurants. The original water boiling test use 5 liter of water for boiling. Our direction is to use the most appropriate container and water quantity. We put our trust on the users to use their cooking appliances in their proper capacity range and use appropriate cookware for the job. For example, the electric kettle used is a small one with maximum water level at 900ml. For microwave oven, we use a thin walled polypropane (PP) food container from restaurants having a volume of 1000ml. So 800ml is natural choice that is close to real life situation.

We are in the process of working out the proper benchmarks. Efficiency and $CO_2$ emission are primary benchmark parameters. For electrical appliances, a coal fired power plant and transmission grid has an overall efficiency of about 30%. For $CO_2$ emission, we can take 0.7kg/kWh. The figures are better if power production is gas fired. For the actual figures, it is best to ask the local electricity supplier. So for electric appliances, efficiency is multipled with local power plant efficiency to get the final result whereas emission is to be multipled with a conversion factor based on actual operating data of the power plant.

Bringing electrical appliances into the scene allows us to see the whole picture before jumping to conclusion. We should not exclude the possibility that one day disadvantaged communities will switch to electricity based cooking solutions. It might even happen that a solar panel can generate the electricity in conjunction with a suitable electric stove to excel in certain situations. Although a solar cooker design is detailed in this paper, which we expect to have high impact as a very good clean cookstove, we shall let the figures be the verdict of any assumptions. Even if it might turn out to be superior in a certain sense today, it might as well turn out to be inferior to a photovoltaic-electrical combination or other solutions under certain circumstances.

A water boiling test that shows each cookstove type in best light can let us make wise deployment or design decisions. Now we get electrical appliances on the racing track, which can stimulate competition between electrical solutions and other cooking solutions. It is also interesting to note that with a 30% power generation efficiency and a 50-90% electrical appliance efficiency, the overall efficiency for electrical solutions is 15-27%, which is about in the middle of other fuel type cooking solutions, making efforts to improve on solutions by either camp worthwhile. Likewise, it is now possible for us to have meaningful benchmark references between photovoltaic and solar thermal solutions alongside others.

Used in another way, this benchmarking by water boiling test can be a source of inspiration for novel combination of energy systems and hint on possible direction of research. Most application involves 1) Conversion from primary energy source to more usable form, 2) Transmission and storage for delivering energy generated, 3) Use in cooking appliance. The overall efficiency is the product of efficiencies for all these stages. Designers can try out different alternatives to explore optimization in the system level or focus on improving a particular step using design and process optimization techniques.

## VI. Deployment considerations

Our aim is to achieve high volume deployment cost-effectively without high investment. Efforts to minimize the mass to be transported for deployment permeates all designs in the library.

Designing with off-the-shelf parts and material means deployment for cities may involve just sending over the design files while materials and parts are purchased locally. In addition, mass-produced materials provide consistent size, safety in use, and certainty of material properties. Combined with good design, it is easy to make it much lighter than designs using local material. The Fresnel reflector using aluminium profile and 0.9mx1.2m polycarbonate sheet mirror weighs less than 2kg, which in turn reduces the weight of both the support and drive mechanism. Even if it is inconvenient to purchase locally, we can ship several thousand units of material in one container, making shipping cost very low.

Making 3D printable tools is another aspect of reducing the mass for deployment. Again, it might involve just sending over the design files and its documentation. Compared with standard workshop machinery, the tools we design are much much lighter and more compact. They can be mailed as a parcel or hand-carried by the deployment personnel so that 3D printer is not needed in the deployment side. They also greatly reduce the upfront investment to set up a batch production line.

Apart from building the library, we intend to spread this Open Source Cookstove Library (OSoCooL) by both centralised deployment and peer-referral, which has the potential to help attain our objective to rapidly spread deployment of the designs. The rich information in the Library to facilitate participation with minimal effort and ease of copying to get quick results are some essential element to spread by personal referral. The easily recognizable shape of the Fresnel reflector and its good, customizable concentrating power with a such simple structure for DIY construction may also help stir up excitement.

The format of deployment we envision is by both consumer product production and humanitarian relief. We have not set any limit to its commercialization. Anyone on earth, including our members, who see a commercial prospect for designs in the library are encouraged to go ahead to try make some money while helping others. On the other hand, the design is optimized for local batch production. This fits very well the humanitarian relief practice of many NGO's and refugee support programs.

A charity foundation may be working with a local community and find clean cookstoves to be a suitable means to help this community. They can take designs from our library, collect the off-the-shelf hardware tools, build the custom tools, buy material, and send it to the destination community, then send people over to carry out the local production and installation. Local production can be done together with young people in the community. The cookstoves may be charged a token price or installment so that the community people will take it seriously as well as serving as maintenance fund. It is also possible for the same batch production practice to be applied to carbon credit trading with the emission reduction being certified and sold to recoup investment and finance future installations. These batch type operations will help further the goal of massive deployment.

## Conclusion

We set out to build an Open Source Cookstove Library (OSoCooL) with the objective of facilitating massive DIY deployment of clean cooking solutions.

A concentrated solar cooker design is elaborated in this paper, plus a brick stove reference design and tools for making beverage can alcohol stoves. The solar cooker design is complemented with a spreadsheet to calculate focal length and focusing spot size of the reflector rings for the designer and a jumbo ring cutter to ensure ring precision and enhance DIY productivity. A series of water boiling test to cover a wide selection of clean cooking solutions is in progress with an aim of providing benchmarks for designers to identify potentially worthy pursues and for implementers to pick the best in state-of-the-art.

The open source designs and the corresponding tools has greatly reduced the entrance barriers for designers to improve on, and for implementers to build the designs. Finally, our project organizing committee are working out ways to encourage trial and deployment using viral marketing techniques.

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